BC/14899-44
DOE/BC/14899--44

MODIFICATION OF RESERVOIR CHEMICAL AND
PHYSICAL FACTORS IN STEAMFLOODS TO INCREASE
HEAVY OIL RECOVERY

Contract Number: DE-FG22-93BC14899

University of Southern California

Contract Date: February 22, 1993

Anticipated Completion Date: February 21, 1996

Government Award (for *current* year): \$150,000

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Reporting Period: October 1 - December 31, 1996

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APR 23 1993
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OBJECTIVES

Thermal methods, and particularly steam injection, are currently recognized as the most promising for the efficient recovery of heavy oil. Despite significant progress, however, important technical issues remain open. Specifically, still inadequate is our knowledge of the complex interaction between porous media and the various fluids of thermal recovery (steam, water, heavy oil, gases, and chemicals). While, the interplay of heat transfer and fluid flow with pore- and macro-scale heterogeneity is largely unexplored.

The objectives of this contract are to continue previous work and to carry out new fundamental studies in the following areas of interest to thermal recovery: displacement and flow properties of fluids involving phase change (condensation-evaporation) in porous media; flow properties of mobility control fluids (such as foam); and the effect of reservoir heterogeneity on thermal recovery. The specific projects are motivated by and address the need to improve heavy oil recovery from typical reservoirs as well as less conventional fractured reservoirs producing from vertical or horizontal wells.

VAPOR-LIQUID FLOW

During this quarter, work continued on the development of relative permeabilities during steam displacement. Two directions are pursued, one based on the use of a pore-network description of steam displacement (1), and another based on a double-drainage process. A model for double drainage which allows for the calculation of three-phase relative permeabilities as a function of the saturation of the respective phases, the history of the displacement and the ratio in interfacial tensions was completed and a M.S. Thesis was written (2). A technical paper is also in preparation. Work also continued in the analysis of the stability of phase change fronts in porous media.

Our investigation of the effect of gravity override during injection of a gas phase (such as steam) in porous media was continued. We developed a fundamental approach using

pore network models to describe the effect of gravity, capillarity and viscous effects on the thickness of the gravity tongue. Our approach utilizes concepts from gradient percolation. For the case of stable displacement, the displacement front is compact and tilted at the angle given by the continuum theory, as expected. For the case of unstable displacement, however, the thickness of the gravity tongue scales as a power-law of the capillary number with exponents given from percolation theory. A cross-over function was developed to capture the scaling behavior in terms of the capillary number and the gravity Bond number. This problem has implications to the prediction of gravity override.

Finally, we are also investigating the countercurrent flow of liquid and vapor in the presence of gravity. This process finds a variety of applications in heavy oil recovery. We are presently interested in the displacement mechanisms which are studied by pore-network simulation and experiments.

HETEROGENEITY

Work continued on the optimization of recovery processes in heterogeneous reservoirs by using optimal control methods. During this quarter, a technical paper on the subject was presented (3). During the past quarter we continued experiments in a Hele-Shaw cell with two controlled injection wells and one production well. Experiments are conducted in homogeneous, as well as heterogeneous cells with a particular form of heterogeneity to test the theoretical predictions. Current work involves further improving the numerical scheme for optimal control. The emphasis is on the effect of heterogeneity on optimal control predictions. In parallel, we used a variation of the control algorithm to solve a novel problem in porous media, namely on how to design the injection rates in a three-well system in order for a parcel of fluid to follow a specific trajectory in the porous medium. This problem finds application in the optimal placement of additives, for example gels, in certain locations in the porous medium. Work in this direction has started in this quarter.

On the subject of heterogeneity, we continued refining the work to explain the origin of stabilized displacements in immiscible displacements in porous media from pore-network level studies (4). Work also continued on the identification of permeability heterogeneity. A technical paper was presented on a new technique that allows the identification of the

permeability semi-variogram from multiple well pressure transients (5). This technique utilizes the theory of small fluctuations, which leads to a Volterra integral equation describing the ensemble-average behavior of the well pressure, from the inversion of which the permeability semi-variogram can be obtained. In addition, we continue our efforts to identify the entire permeability field from tracer profiles (e.g. those obtained from a CT scan). We have developed an algorithm, which is still being tested with synthetic data.

CHEMICAL ADDITIVES

In the area of chemical additives work continued on the behavior of non-Newtonian fluid flow and on foam displacements in porous media. As pointed out in our previous report, work in this area proceeds in two parallel directions: One involves the development of a generic theory for finding a hierarchy of minimum threshold paths in a disordered system. A technical paper was written on this subject (6). This theory was then applied to pore networks to determine the conditions for foam formation and mobilization. A technical paper summarizing the results was written (7). This work shows how to compute parameters related to foam flow in porous media, such as the minimum pressure gradient for onset of foam flow, the fraction of trapped foam, etc. The work is now extended to the problem of Bingham plastic flow in porous media.

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